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Abstract

We describe experiments which investigate convection effects on hydrogen ice layers in a transparent CH capsule suspended with a fill-tube. These experiments validate simulations which show that unmitigated convection from the hohlraum fill gas can produce significant distortions to the cryogenic hydrogen ice layer. Experimental results show good agreement with thermal simulations which include conduction and convection.

Introduction

Current designs for NIF indirect drive ignition targets consist of a cryogenically cooled fuel capsule suspended in the center of a hohlraum\cite{haan,bodner,lindl}. The fuel capsule consists of an ablator shell with a layer of DT (deuterium-tritium) ice on the inside. The hohlraum is filled with a mixture of He/H2 gas at a density of 1 to 3 mg/cc. High intensity laser beams pass through the laser entrance holes (LEHs) and through the gas to strike the hohlraum inner wall where they are converted to x-rays which illuminate the fuel capsule. The capsule implodes compressing and heating the DT to conditions sufficient for thermonuclear fusion. One requirement for significant fusion energy yield is that the initial DT ice layer be sufficiently smooth so as not to seed Rayleigh-Taylor instabilities which can disrupt the compression of the fuel layer.

Heating of the hohlraum fill gas near the fuel capsule via tritium beta decay results in buoyancy of the gas due to the gravitational potential. The gas rises and sets up convection cells in the hohlraum. This convection produces a change in the thermal environment and heating/cooling of the fuel capsule and DT ice. We have modeled this convection for real hohlraum parameters and find that the convection is strong enough to alter the shape of the DT ice layer making it unacceptable for ignition.

As a way of mitigating this convection we have worked with Luxel corporation to develop a method of installing thin film baffles inside the hohlraum which break up the convection cells substantially decreasing their effectiveness at distorting the temperature isotherms in the ice layer.

We have developed two experiments for the purpose of experimentally investigating convection relevant to a NIF ignition hohlraum. One experiment, which uses a hohlraum target and is still under construction, is designed to test the baffle technique for suppressing convection effects. A second experiment uses a target consisting of a fuel shell suspended in the center of an integrating sphere by a fill tube. The region surrounding the shell is filled with various pressures of He gas and the resulting distortion on the ice layer inside of the shell is measured using shadowgraphy. We find that there is good agreement between the measurements and simulations for the spherical geometry experiment.

Experimental setup

The experiment consisted of measuring the effect of natural convection on the HD ice layer in a 40 μm CD shell suspended by a fill tube in an integrating sphere. This is the same target used for the work described in IDI 4.4.1:03:4. Figure 1 shows a schematic of the experiment.

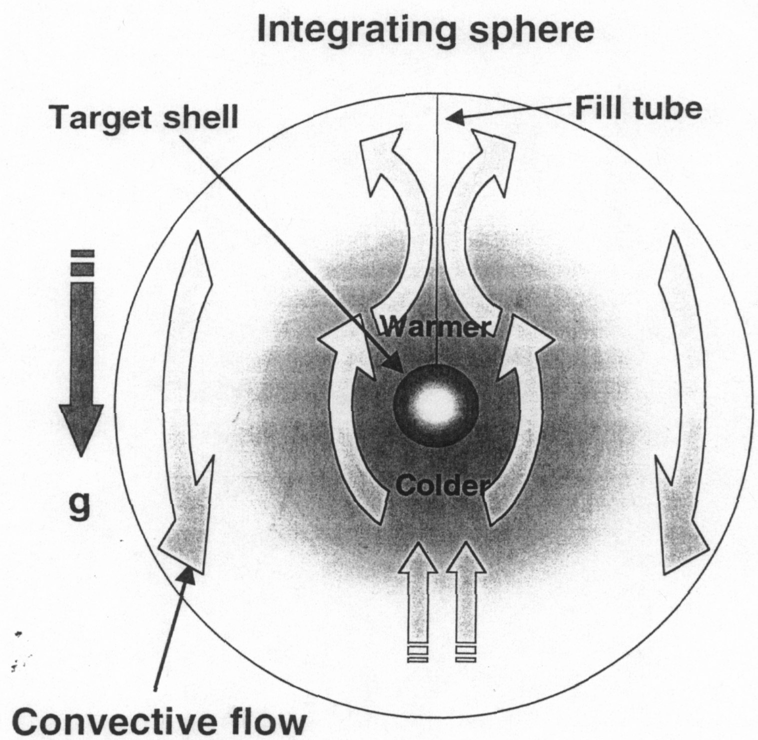

Figure 1. Schematic showing the experiment to investigate convection in spherical geometry.

The ice is heated via IR injection into the integrating sphere and heats the He gas surrounding the shell. The gas expands and becomes buoyant due to gravity. As the gas rises it develops a toroidal convection cell. The He gas is cooled as it flows down along the integrating sphere and is warmed as it flows past the shell. This convection is expected to create a temperature gradient in the shell with the lower part cooler than the upper part. The ice is expected to respond to this gradient and become thicker at the bottom and thinner at the top.

The strength of natural convection is determined by the Grashoff number which is defined as

$$Gr \propto \frac{\rho^2 \cdot g \cdot L^3 \cdot \beta \cdot \Delta T}{\mu^2}$$

where ρ is the gas density, g is gravitational acceleration, L is the scalesize of the enclosed region, β is the thermal expansion coefficient, ΔT is the typical temperature variation, and μ is the viscosity. The Grashoff number for the sphere experiment is about 2 to 3 times as large as the Grashoff number for the hohlraum. Thus, the sphere experiment is in a similar parameter regime.

Experimental results

Figure 2 shows the shadowgrams indicative of the inner surface of the ice for the case where there is no natural convection and where there is a significant effect.

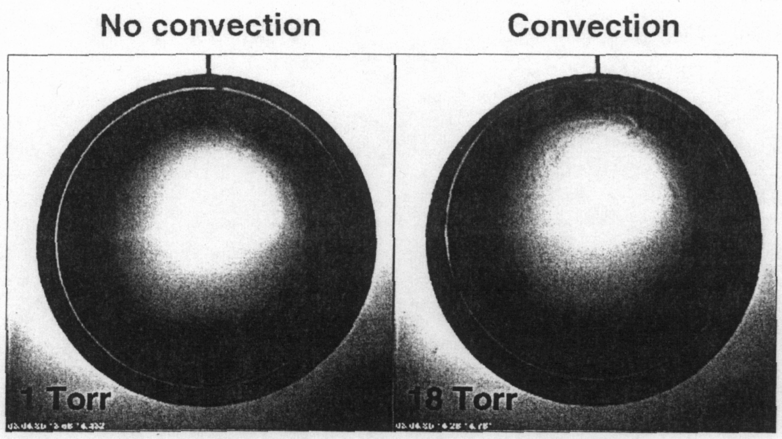

Figure 1. Shadowgraph images showing the location of the bright band without convection and with convection. Convection causes the ice layer to become thicker at the lower part of the shell and thinner at the upper part of the shell.

The effect of natural convection was quantified by measuring the displacement of the bright band at the location opposite to the fill tube as a function of IR heating rate and He fill pressure. Figure 3 below shows the result of these measurements for two different IR heating rates.

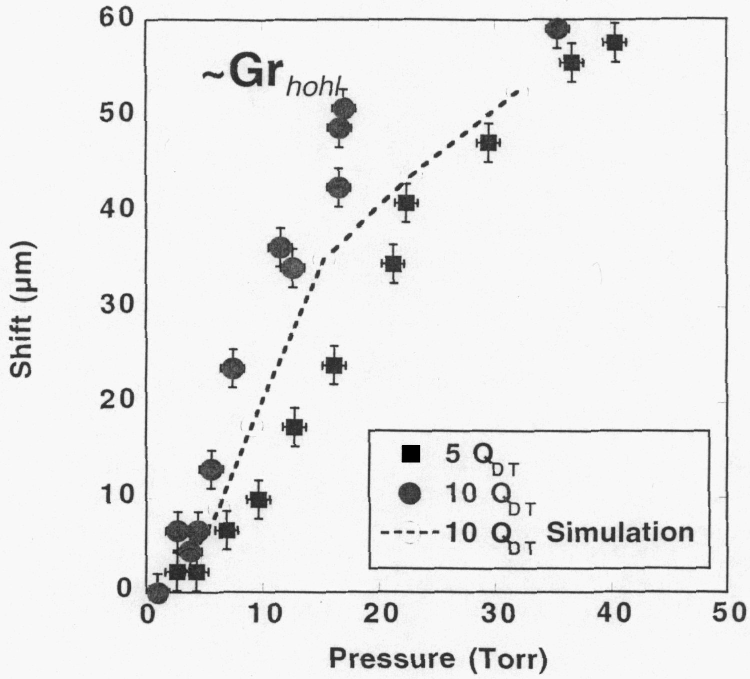

Figure 2. Plot shows the shift of the bright band as a function of He pressure for 5 Q_{DT} and 10 Q_{DT} of IR heat input into the ice layer.

Both cases show a steady increase in the shift until about 20 to 30 Torr of He pressure when the shift begins increasing at a slower rate. The ice layer has limited thickness and at a shift of about 40 to 50 µm the inner ice surface begins to distort away from a sphere.

Simulations

Simulations of the experiment were done using the COSMOS thermal transport/flow model. We created several models having a shell centered in an integrating sphere with an ice layer offset vertically by a fixed distance. The He fill pressure was increased until the temperature variation on the inner ice surface was minimized. Doing this for models with several different vertical ice offsets gave the points plotted in Fig. Blah above for the offset versus He pressure. The difference between the simulation and measurement is probably due to the uncertainty in the power absorption of the shell. We estimated that 40% of the power absorbed by the ice is also absorbed by the shell. However, this number is uncertain and could be between 20% and 60%.

Conclusions

We conclude from this that the COSMOS model is accurately calculating natural convection in the sphereical geometry. By induction and the fact that the Grashoff numbers between the spherical case and the hohlraum are within a factor of 2 to 3 it is reasonable to assume that we are calculating the convection in the hohlraum correctly. The hohlraum experiments will be able to confirm this.